

# DER Roadshow

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## Advanced Reciprocating Engines

Gordon Gerber  
ARES Program Manager  
Caterpillar Inc

Gerber\_Gordon\_R@Cat.com



# Caterpillar Power Products

Solar Turbines

MaK

3600

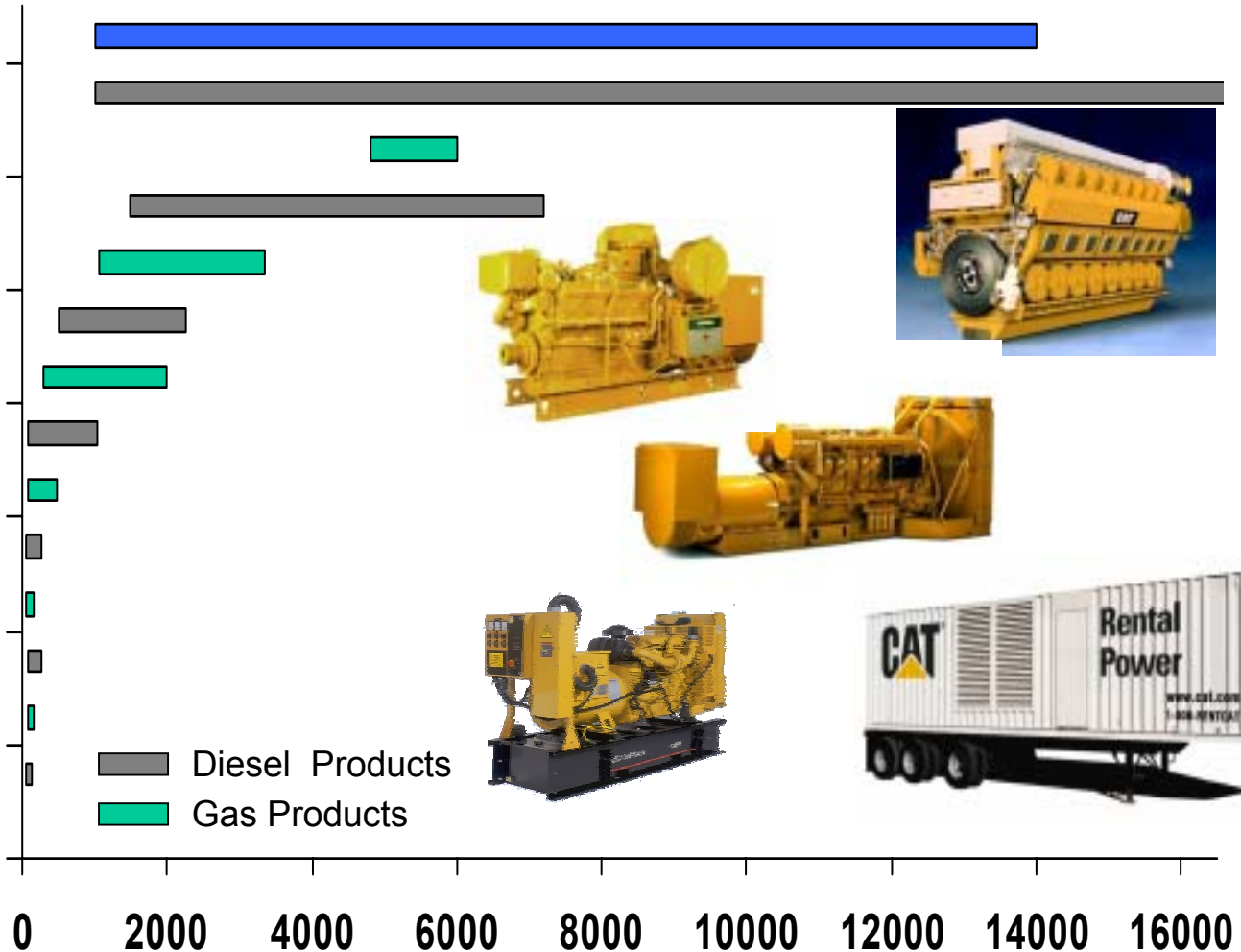
3500

3400

3300

3100

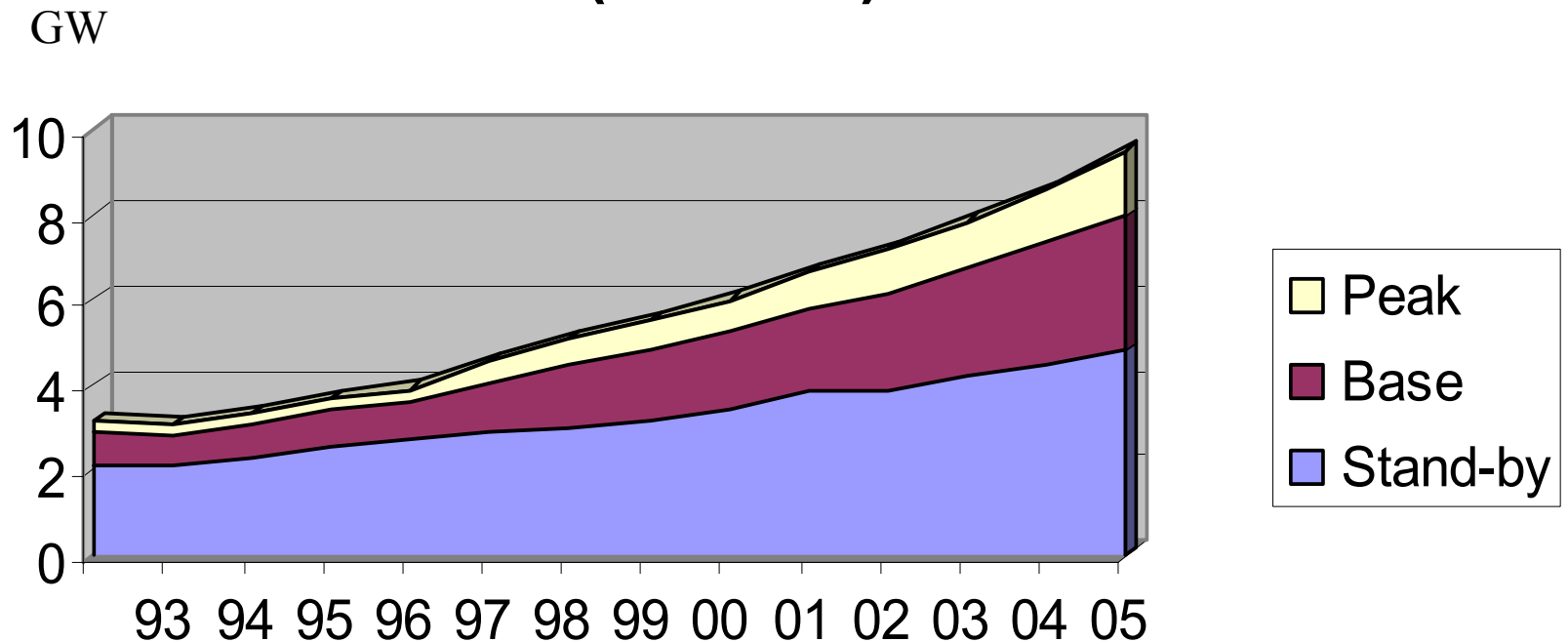
3000



Package Power ekw

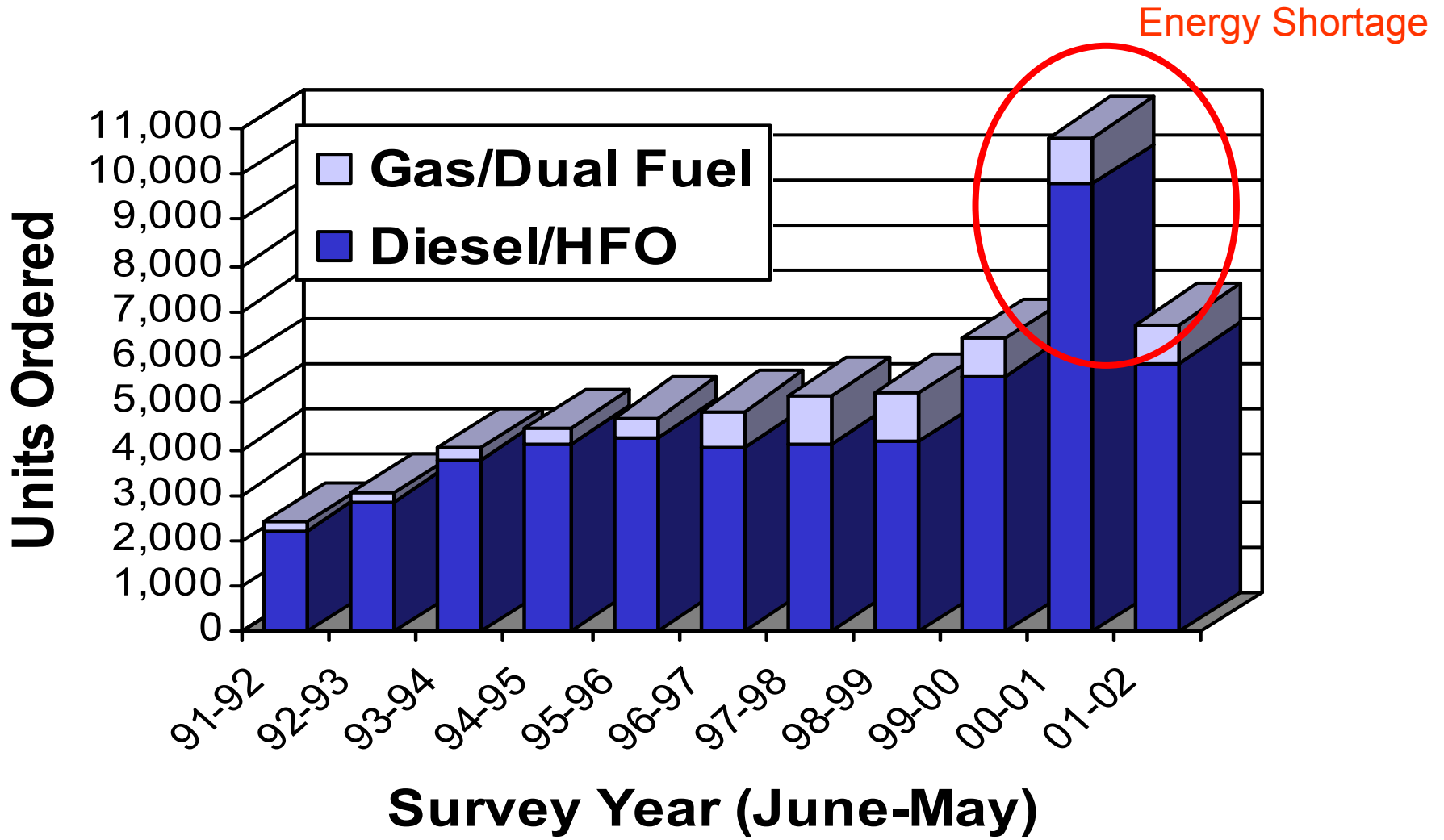
# Market Growth Trend

## North American Recip & GT Sales (<20MW)



Source: A.D.Little

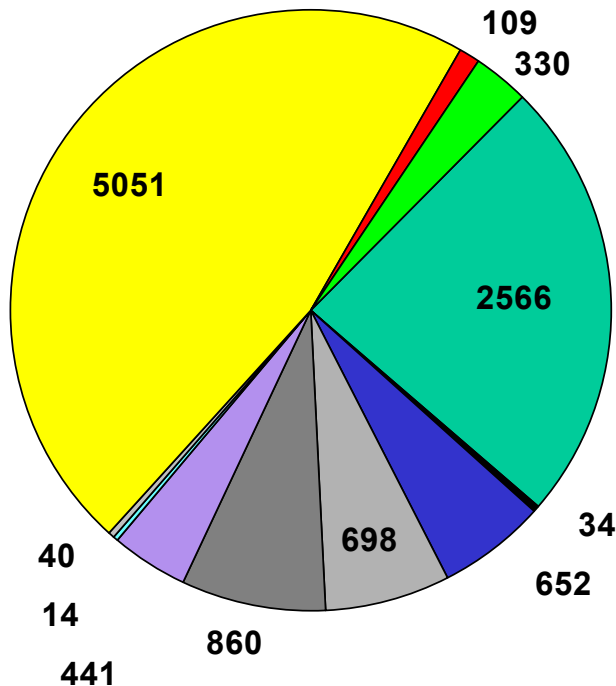
# Engine Power Growth Trend 1MW-30MW



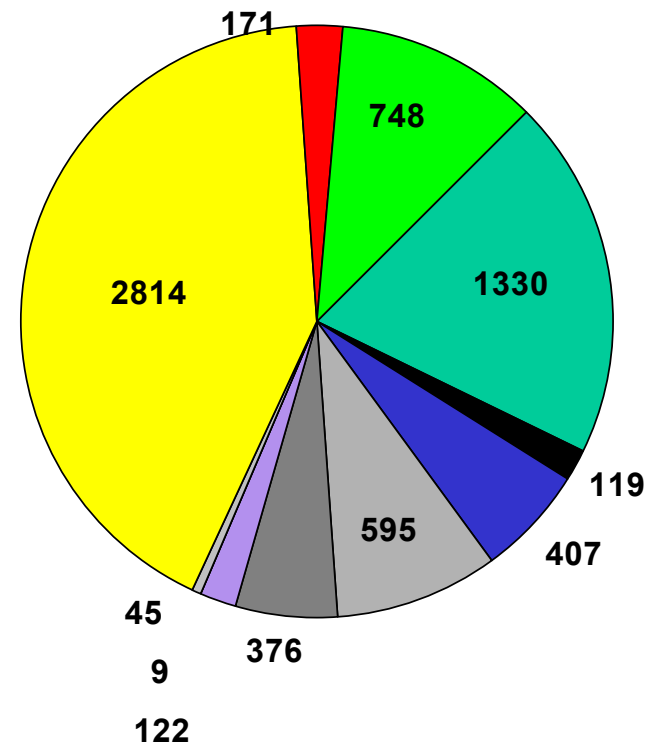
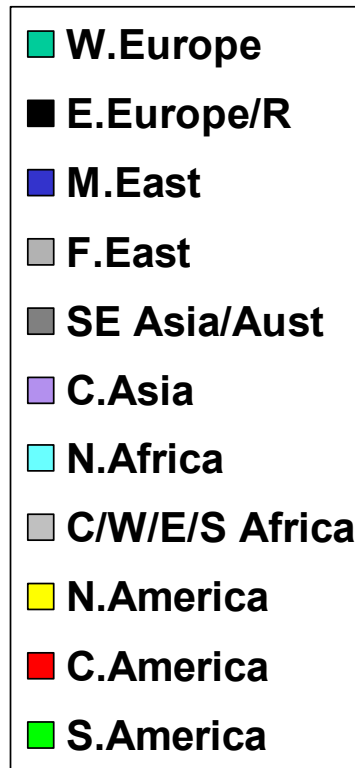
10 yr Total = 50,939 Engines  
1MW – 30MW Class

Diesel & Gas Turbine Worldwide, Oct 2002

# Engine Applications Worldwide



2000-2001  
10,795 Units

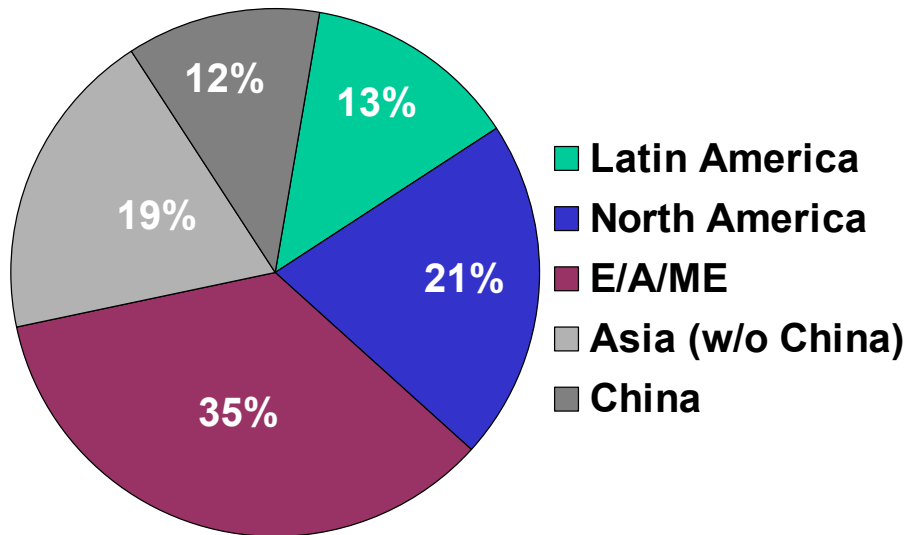


2001-2002  
6,736 Units

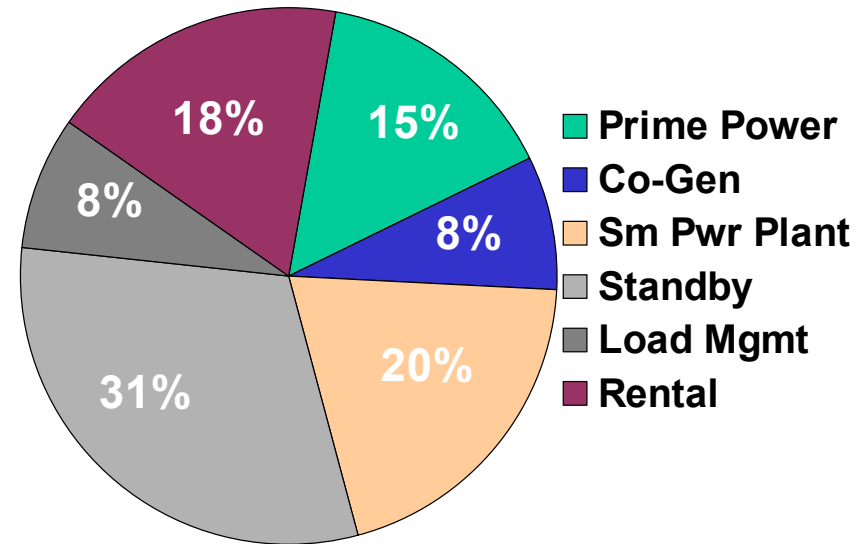
# GenSet Applications Worldwide

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**Location**  
(units)



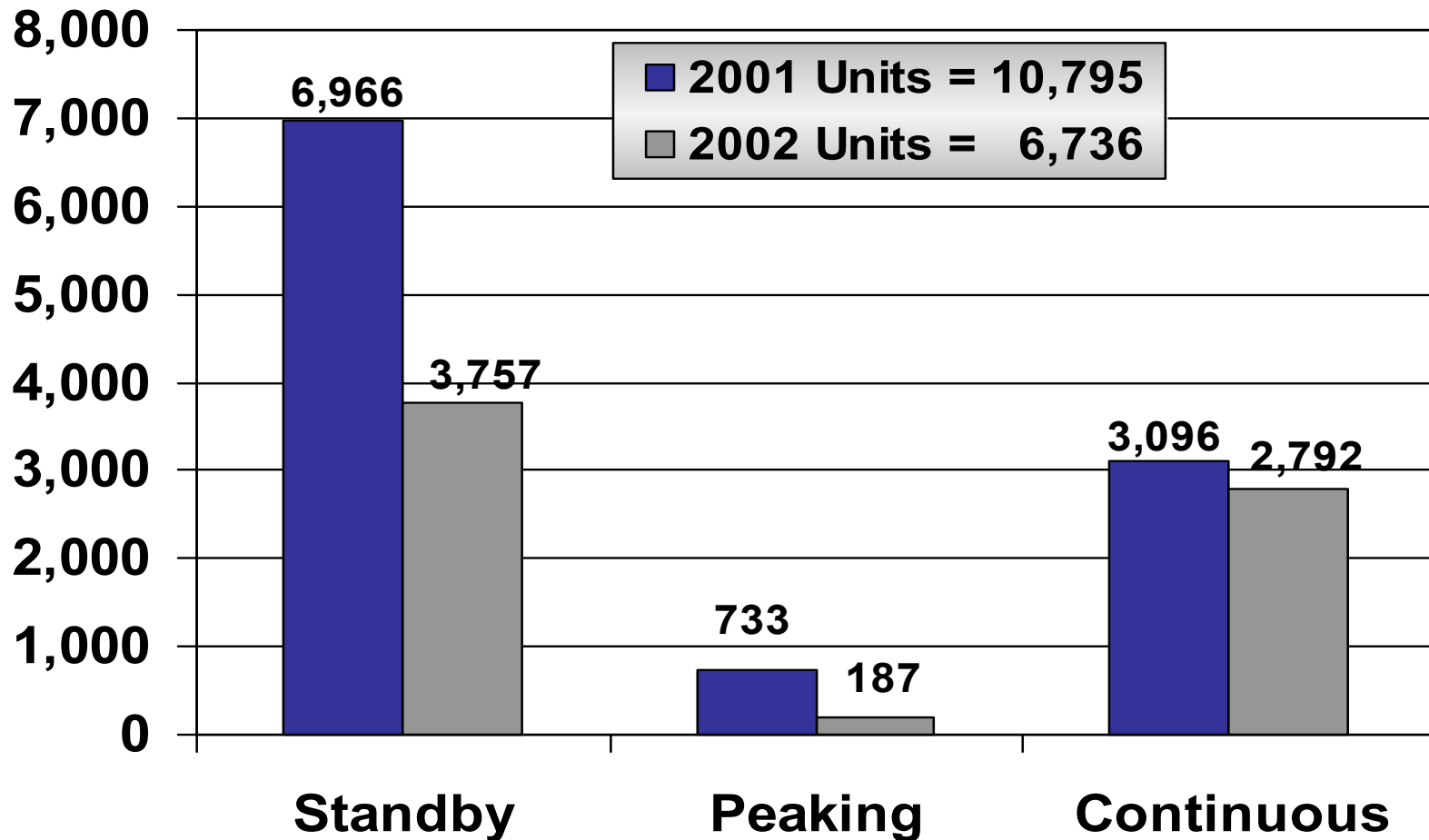
**Application**  
(dollars)



Source: Caterpillar Electric Power, 2001

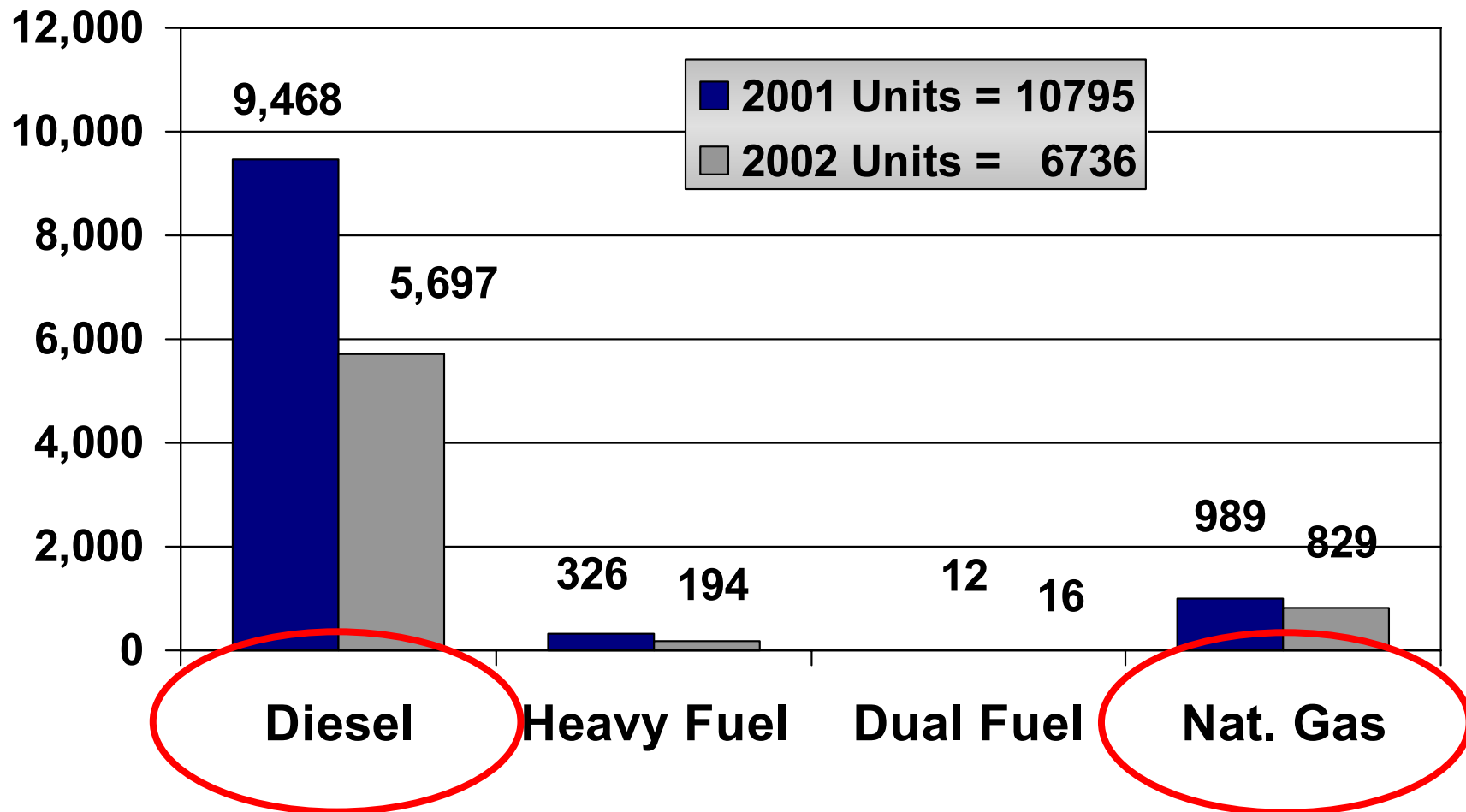
# Engine Applications by Service

No. of Engines, 1MW - 30MW




# Engine Applications by Fuel

No. of Engines, 1MW - 30MW





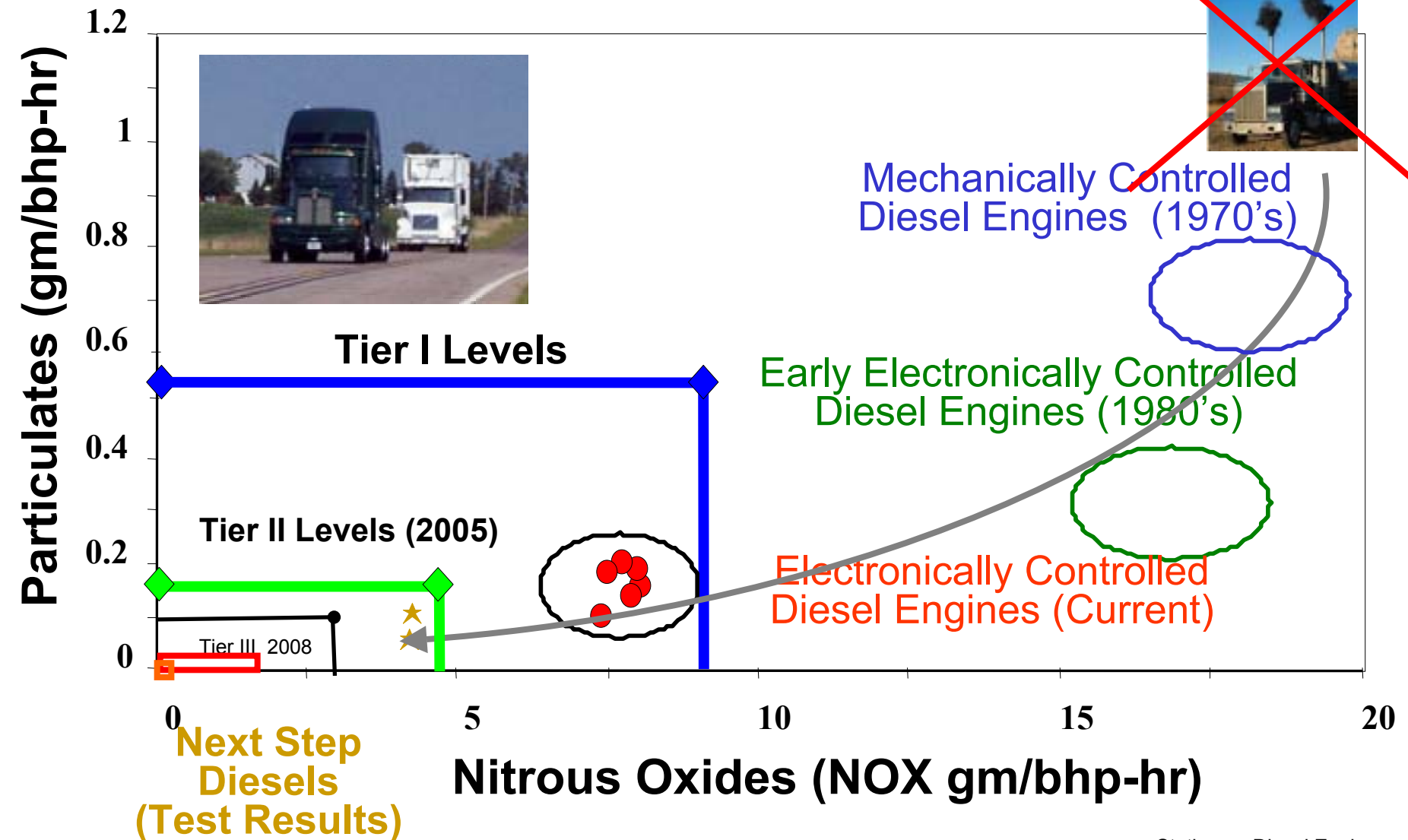
# Advanced Diesel

Technology Comparison	Diesel Recip	Gas Recip	Simple	Micro-	Fuel Cell	Photo-voltaics
Size Range (eKW)	20 – 10,000	50 – 5000				
Efficiency HHV	36- 43 %	28-46 %				
*Genset Pkg Cost	125 – 300	250-600				
*Turnkey w/o Heat Rec	350-500	600- 1000				
*Heat Recovery	n. a .	75 – 150				
*O & M Costs	.005 - .01	.007 - .015				

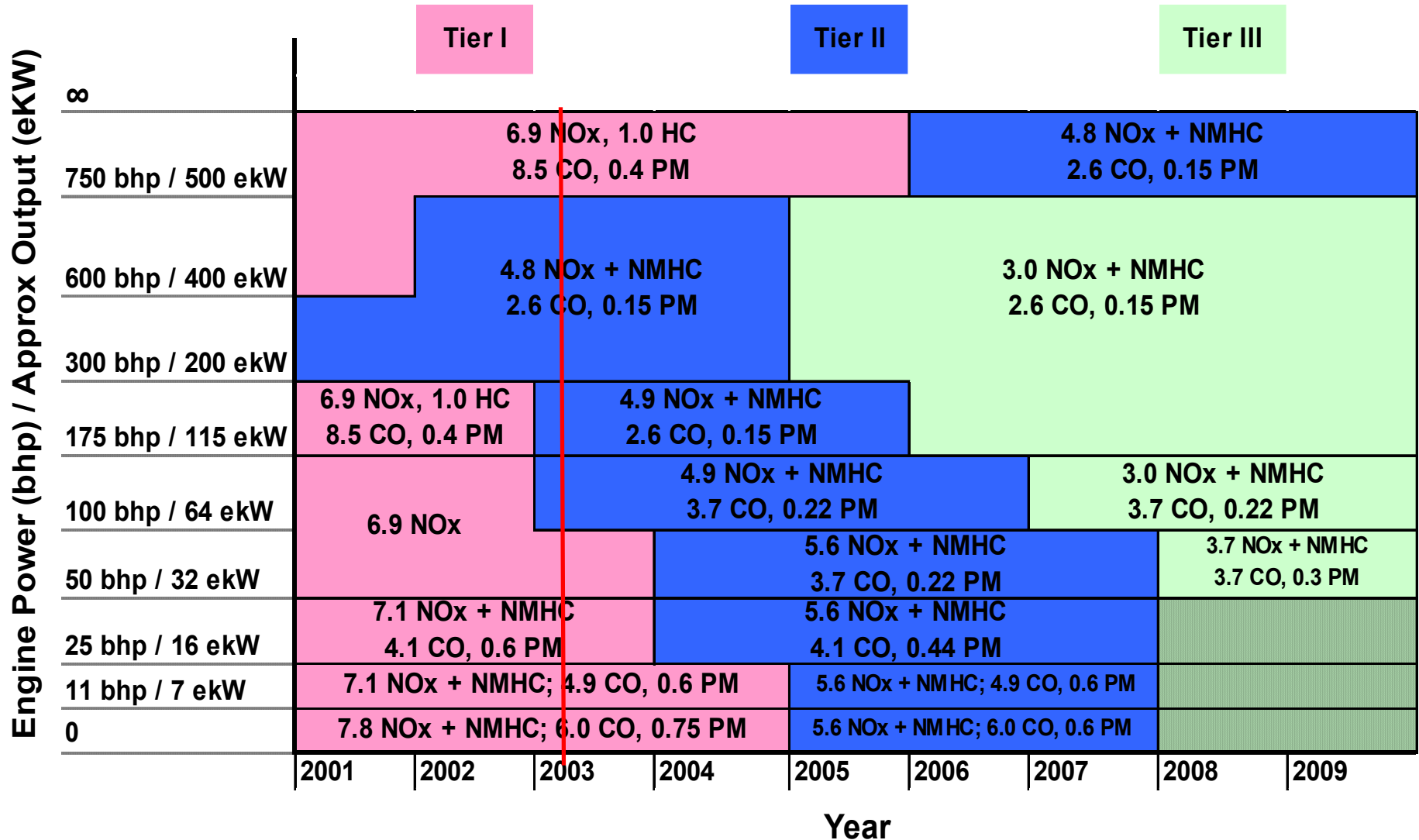
\* Cost in \$/eKW

Source -- GTI Distributed Generation Forum 2000

# Mobile Diesel Progress



# Stationary Diesel Emissions



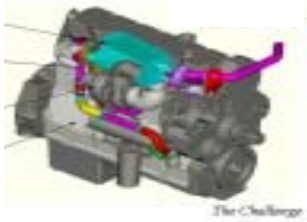
Requirements < 500 ekw

# Advanced Diesel Technologies

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Emissions Requirement	Feasible Diesel Technologies
EPA Non-Road Tier I NOx = 6.9 g/bhp-hr	All Electronic Engines and Many Mechanical Engines with Jacket Water Aftercooling
EPA Non-Road Tier II NOx+NMHC = 4.8 g/bhp-hr	Electronics with Air-to-Air or Liquid Aftercooling
EPA Non-Road Tier III NOx+NMHC = 3.0 g/bhp-hr	Electronics with Cooled EGR & Air-to-Air Aftercooling, or ACERT Combustion Technology, or Electronics with Precise Injection Control, SCR Aftertreatment & Air to Air Aftercooling
EPA Non-Road Tier IV (Assumed) NOx = 1.0 g/bhp-hr	Cooled EGR & Flexible Fuel Injection & Combustion Development, or ACERT + Improved Air Systems, or Additional SCR Aftertreatment
EPA Non-Road Tier V (Assumed) NOx = 0.5 g/bhp-hr	Best Combustion & Closed Loop SCR

# Advanced Diesel Concepts



Technical Path	Fuel Rate	Complexity	Cost / kw
Electronic Injection	✓	↔	✓
Separate Circuit Aftercooling	↔	✗	✗
Exhaust Gas Recirculation	✗	✗	✗
Ultra-Precise Injection Control	✓	↔	↔
Aftertreatment (SCR or Particulate Traps)	↔	✗	✗

# Advanced Diesel Results

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## ACERT™: Advanced Combustion Emissions Reduction Technology

- 50% NOx Reduction 1998 - 2002
- Building Block for Near Zero Emissions
- Combination of
  - Tailored Combustion
  - Improved Controls
  - Precise Injection
  - Dedicated DOC (Direct Oxycat)
- EPA Compliant Throughout 2003
- Technology transfer into stationary electric power, construction equipment, marine, and locomotive.



# Advanced Natural Gas

Technology Comparison	Diesel Recip	Gas Recip	Simple Cycl Gas Turbine	Micro-turbine	Fuel Cell	Photo-Voltaics
Size Range (eKW)	20 – 10,000	50 – 5000	1			
Efficiency HHV	36- 43 %	28-46 %	2			
*Genset Pkg Cost	125 – 300	250-600	3			
*Turnkey w/o Heat Rec	350-500	600- 1000	6			
*Heat Recovery	n. a .	75 – 150	1			
*O & M Costs	.005 - .01	.007 - .015	.			

Gas Infrastructure

Cost/kw

Emissions

Product Availability

Complexity

\* Cost in \$/eKW

Source -- GTI Distributed Generation Forum 2000



# Natural Gas Applications

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Waukesha at NW Community Hospital (IL): 3MW: CHP & Peak Shaving

Many Applications Today



Caterpillar at Temple University (PA): 16 MW: Peak Shaving



Waukesha at Tampa Electric (FL): 7 MW: CHP & Peak Shaving



Cummins St. Catherine's General Hospital (Ontario): 2.5 MW CHP



Caterpillar at Navistar (MI): 9 MW: CHP



# Diesel – Natural Gas Comparison

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## Diesel – Gas Installation Comparison 400 ekw



Diesel Fuel Storage  
Smaller Radiator /kw  
Smaller Volume /kw  
Lighter /kw  
Lower Cost /kw



Gas Piping / Pressure  
Larger Radiator /kw  
Larger Volume /kw  
Heavier /kw  
More Expensive /kw

# Diesel – Natural Gas Comparison

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## Diesel – Gas Operational Comparison 400 ekw



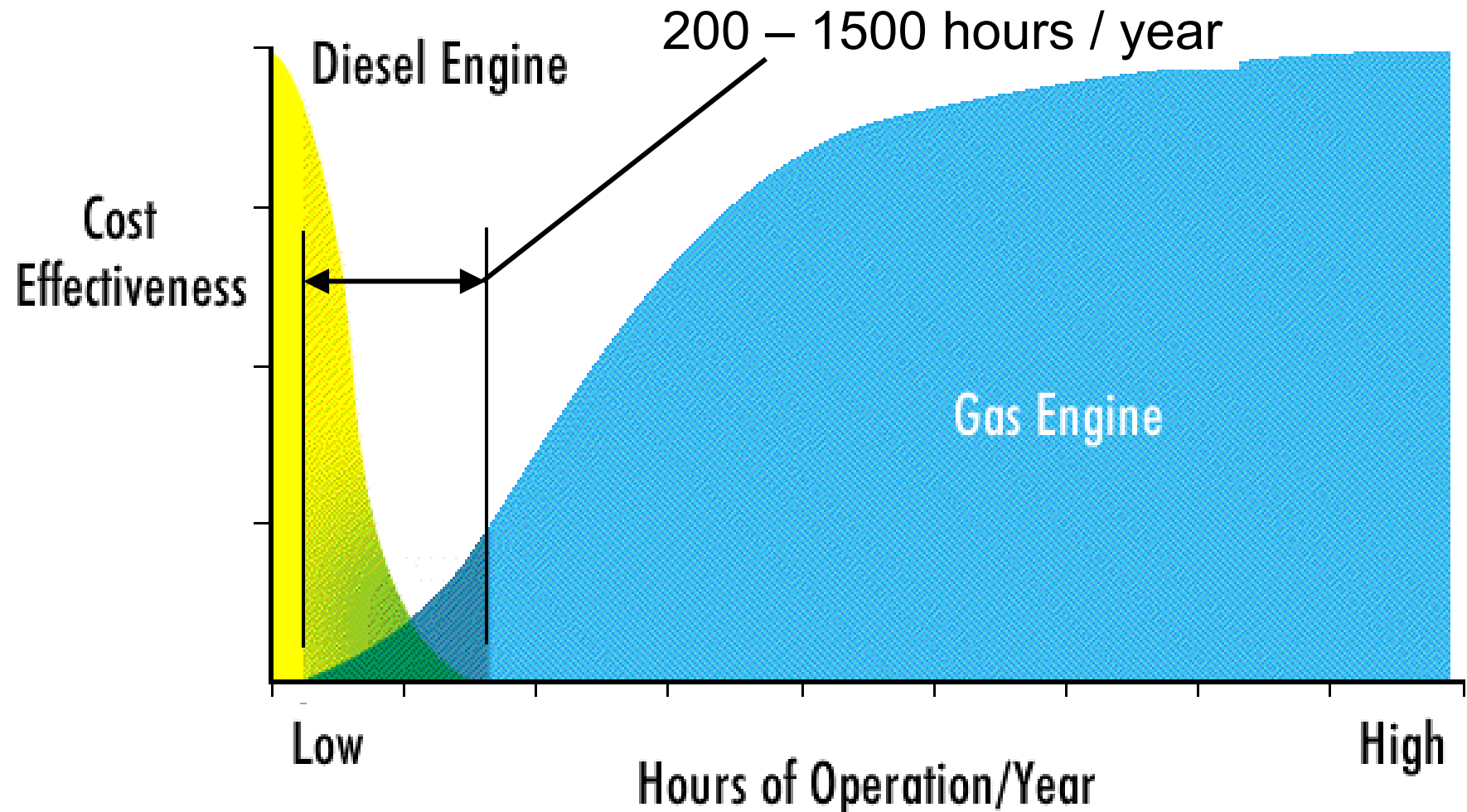
<10 sec Full Load Time  
Good Block Load Response  
Fast Transient Response  
Higher Noise to Reduce  
Higher NOx emissions  
Higher Fuel Costs  
Lower Maintenance Costs



10 - 30 sec Full Load Time  
Adequate Block Load  
Variable Transient Response  
Lower Noise to Reduce  
Lower NOx emissions  
Lower Fuel Costs  
Higher Maintenance Costs

# Fuel Type by Application

## Diesel – Gas Life Cycle Cost Comparison



# ARES Program

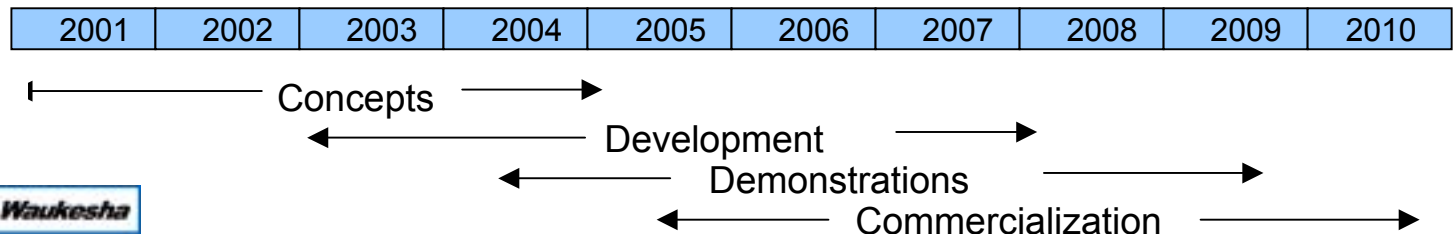
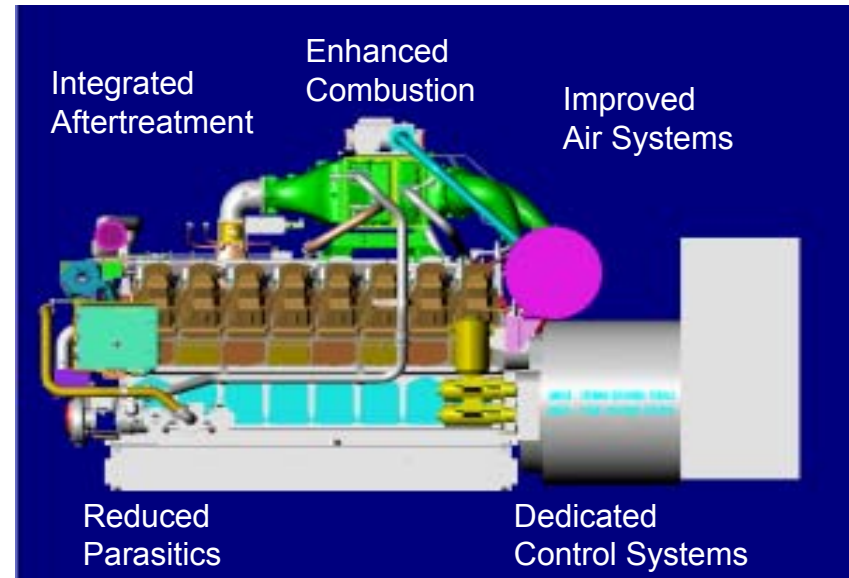
Advanced Reciprocating  
Engine Systems



A multiyear cooperative agreement between the US Dept of Energy and Industry to create a 50% efficient natural gas powered reciprocating engine system with a 95% reduction in NOx emissions by the year 2010



- ▶ Multiple Phases
- ▶ Ongoing Market Verification
- ▶ Partnerships with Labs / Universities
- ▶ Pre-Commercialization Demos
- ▶ Full Commercialized Production
- ▶ Awards Announced Nov 2000
- ▶ Contracts Signed April 2001
- ▶ Phase 1 Complete 2004-2005
- ▶ Phase 2 Complete 2007-2008
- ▶ Final Phase Complete 2009-2010



# ARES Program

Advanced Reciprocating  
Engine Systems

## Typical Introduction by Phases: Staged Introductions Faster Time to Market Quicker Program Results

Current 38-40% BTE, 2 g NO<sub>x</sub>

Phase I 44% BTE, 0.50g NO<sub>x</sub>

Phase II 47% BTE, 0.1g NO<sub>x</sub>

Phase III 50% BTE, 0.1g NO<sub>x</sub>

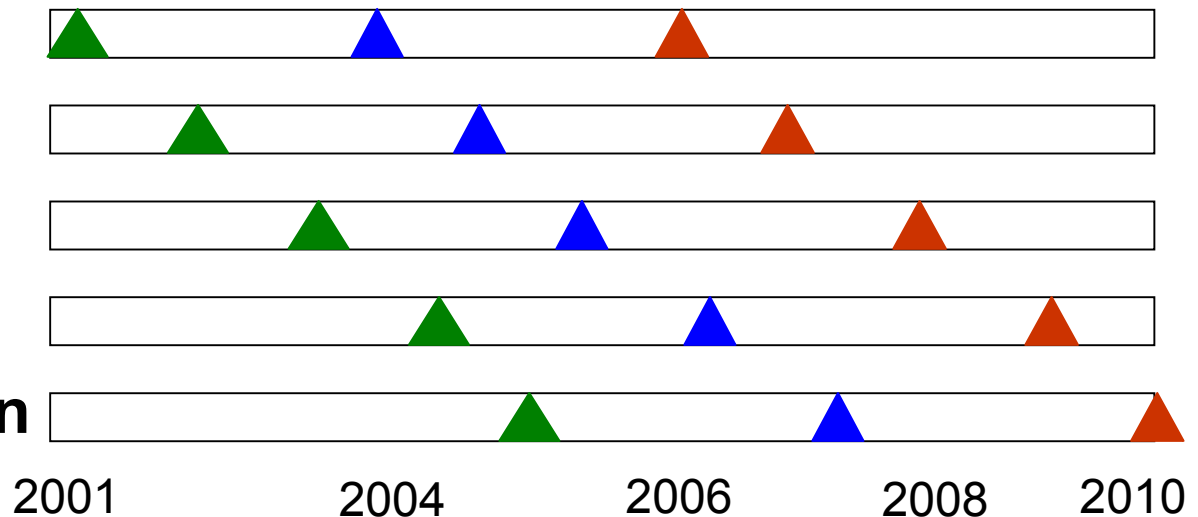
Concepts

Technical Base

Platform Base

Field Demos

Commercialization

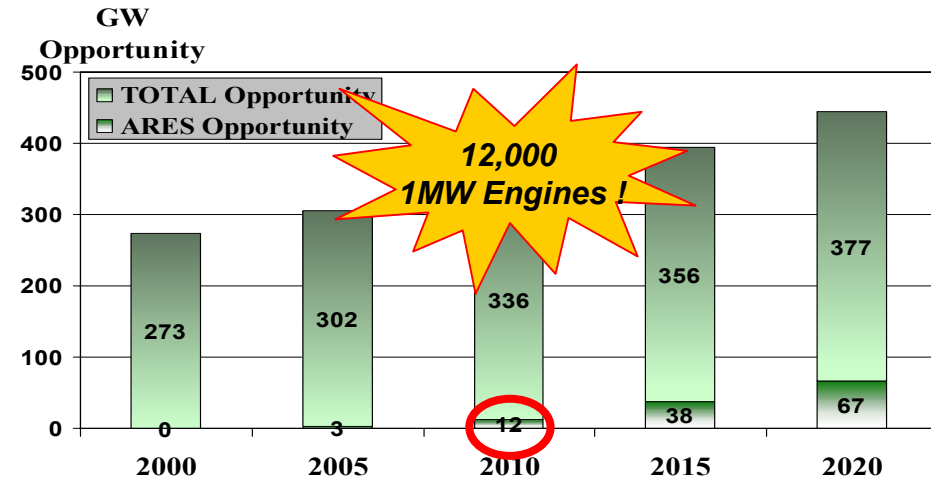


# ARES Program Results

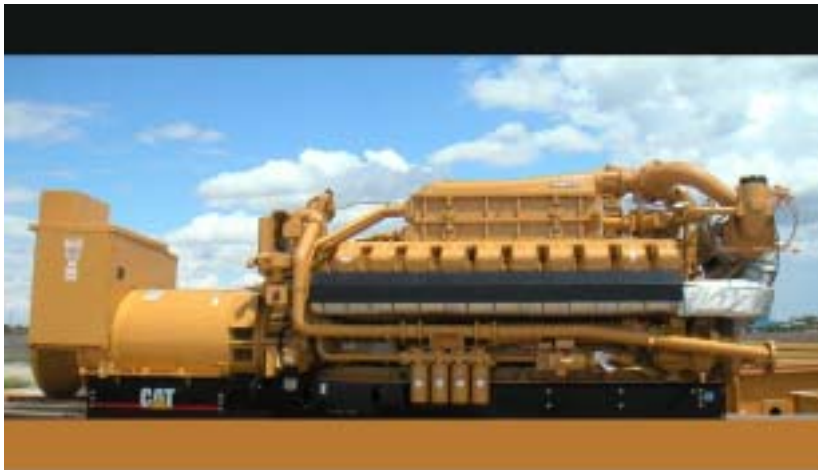


✓ Market Study Done

- Technology Overview
- ARES Growth Potential



[www.eere.energy.gov/der/pdfs/ recip\\_engines\\_conf\\_02/bluestein.pdf](http://www.eere.energy.gov/der/pdfs/ recip_engines_conf_02/bluestein.pdf)

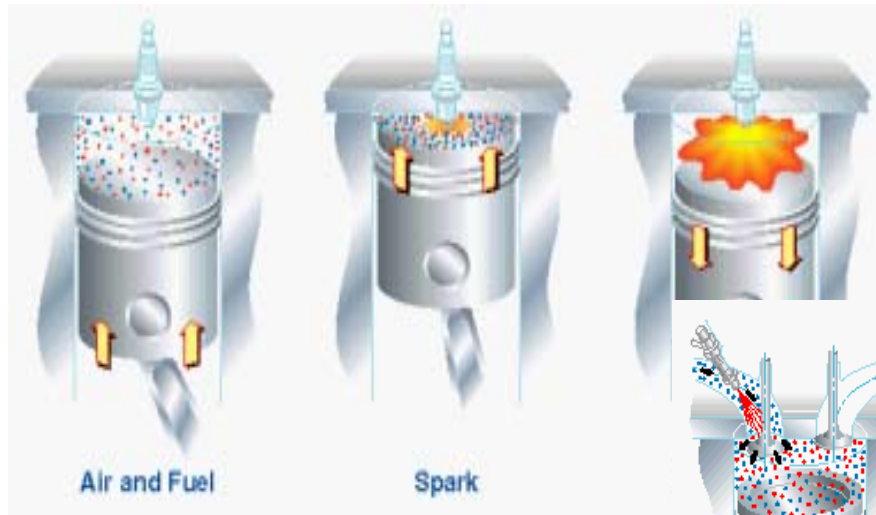


First early ARES Product  
Caterpillar G3520C

- 10% better fuel economy
- 40% better power density
- 10% lower maintenance cost / kw
- No loss of emissions or first cost
- Available February 2003

# Advanced Natural Gas

## Long Term ARES Combustion System - HCCI

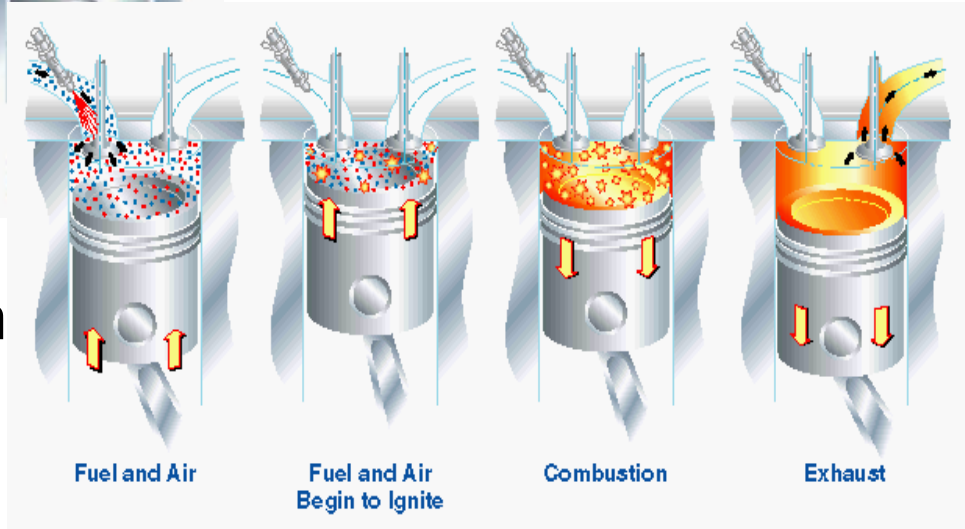


Normal SI Combustion

50% + Efficiency

<< 0.1 g/bhp-hr NO<sub>x</sub>

Equivalent Power Density



HCCI Combustion

# Advanced Reciprocating Engines

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- ✓ Diesel Engines offer dramatic emissions improvements
  - Mobile and stationary applications
  - Predictable life cycle costs
- ✓ Natural Gas Engines offer improved systems performance
  - Increasing power density and lower emissions
  - DOE - ARES program execution
- ✓ Engines will continue to contribute to growing US power needs

THANK YOU!  
QUESTIONS?

